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Airframes and Engines Division
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ABSTRACT

This report focuses on the field trial of a GPS unit for measuring low helicopter airspeeds. The results indicated that the GPS has the potential to be used as a low-speed indicator. However, the possible loss of GPS signal, transient GPS results due to changes in satellites being used for the solution, time lag in the results and whether the assumption of a constant wind-speed is valid need to be considered.

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Executive Summary

The original equipment manufacturer usually specifies the retirement lives of fatigue life-limited structural components based on assumed usage spectra that are dependent on the aircraft's mission profile and flight loads. Helicopters, however, are often not used in the same mission profiles as assumed when they were designed. Thus the retirement lives assigned to components could be too high or too low, leading to safety concerns or higher than necessary operating costs. By monitoring the actual mission profile of each helicopter, the most optimal component retirement lives can be calculated. This is known as Usage Monitoring.

Usage Monitoring aims to identify how the helicopter is used and estimates when components need to be replaced by estimating the remaining fatigue lives for the components. Flight condition monitoring, a technique of usage monitoring, involves the recording of various aircraft parameters from which flight conditions can be deduced. A key parameter for flight condition monitoring is the helicopter's airspeed. Airspeed is normally obtained via pitot-static tubes mounted near the front of the helicopter. However, if the helicopter is travelling at less than 30 knots then the pitot-static tubes are within the downwash from the rotor blades giving an error for the airspeed readings. This low-speed regime consisting of forwards, sideways, and rearwards flight, is significant in terms of the fatigue damage experienced by components. Since the readings from the pitot-static tubes are not reliable at speeds below 30 knots, another method of determining the helicopter's speed is required.

This report focuses on the field trial of a Global Positioning System (GPS) unit for measuring low helicopter airspeeds. Though the GPS results indicated that it has the potential to be used as a low-speed indicator, certain issues need to be considered. These include possible loss of GPS signal, transient GPS results due to changes in satellites being used for the solution, time lag in the results, and possible error in the assumption of a constant wind-speed. Though not our focus, it was found that the GPS unit uses Doppler shift of the carrier frequency to calculate velocity rather than distance over time.

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1. Introduction

1.1 Background

An aircraft manufacturer usually specifies the retirement lives of fatigue life-limited structural components based on assumed usage spectra that are dependent on the aircraft's mission profile and measured flight loads. Over their service life, helicopters, due to their versatility, are often not used in the same mission profile as assumed when they were designed. These changes in mission profile have implications for the retirement lives assigned to components. The lives could be too high, leading to safety concerns, or too low, leading to higher than necessary operating costs. A means of determining the actual damage incurred by components is therefore desirable. One possible solution is to monitor the mission profile of the helicopters and recalculate the retirement times based on the actual type of flying being undertaken. This monitoring could be continuous or done at intervals. A monitoring device could be installed that establishes the type and duration of manoeuvres flown allowing for an adjustment of the retirement lives of the components. This is known as Usage Monitoring.

Usage Monitoring aims to identify how the helicopter is being used and tries to estimate how much fatigue life remains for specific components before they need to be replaced. There are two main ways of conducting usage monitoring; loads monitoring and flight condition monitoring. Flight condition monitoring is the more common method, and involves the recording of various aircraft parameters from which flight conditions can be deduced. To convert information about flight conditions into fatigue damage for a particular component, a relationship is required between each flight condition and the resulting flight loads on that component. This relationship is generally obtained by conducting a comprehensive flight test program on a fully instrumented aircraft. The aircraft is flown through each flight condition and the required component loads are recorded.

A key parameter for flight condition monitoring is the helicopter's airspeed. Knowledge of the airspeed is therefore important. This report outlines one potential method for measuring low helicopter airspeeds, where the normal airspeed sensing system does not work adequately.

1.2 Helicopter Airspeed Measurement

Airspeed is normally obtained via pitot-static tubes mounted near the front of the helicopter. If the helicopter is travelling faster than approximately 30 knots (56 km/h), then the speed indication works accurately as the pitot-static tubes are not in the downwash of the rotor system (Figure 1). However, if the helicopter is travelling at less than 30 knots then the pitot-static tubes are within the downwash from the rotor blades giving an error for the airspeed readings (Figure 2). For some helicopters, this slow-speed regime (which consists of forwards, sideways, and rearwards flight), is significant in terms of the fatigue damage experienced by components. Since the readings from the pitot-static tubes are not reliable at speeds below 30 knots, other methods of determining the helicopter's speed are required.

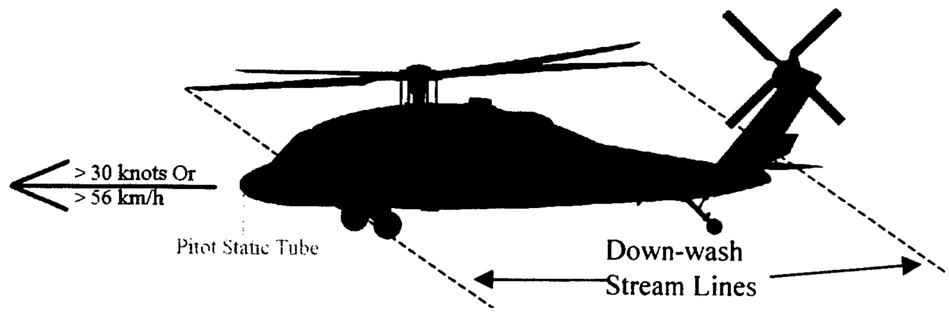

Figure 1: Speed Greater than 30 knots - Downwash has no affect on Pitot Static Tube readings

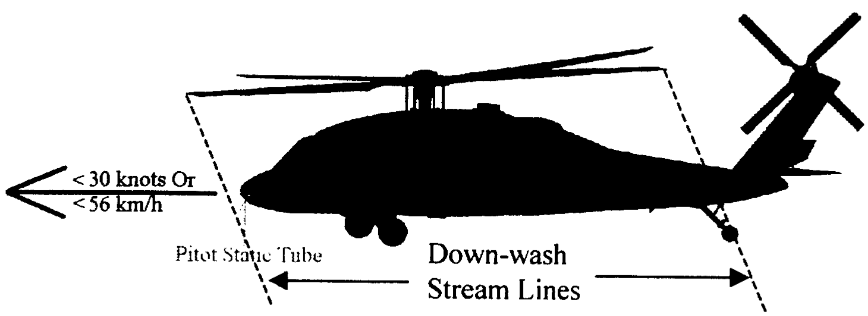

Figure 2: Speed Less than 30 knots - Downwash affects Pitot Static Tube readings

1.3 GPS as a Low Airspeed sensor.

The Global Positioning System (GPS) can be used to obtain a helicopter's ground speed. However, as the required parameter for flight regime recognition is airspeed, not ground speed, the use of the GPS as a system for measuring low airspeed will require knowledge of the wind speed. The relationship between airspeed and ground speed is a simple vector sum as shown below:

$$\overrightarrow{GroundSpeed} = \overrightarrow{AirSpeed} + \overrightarrow{WindSpeed}$$

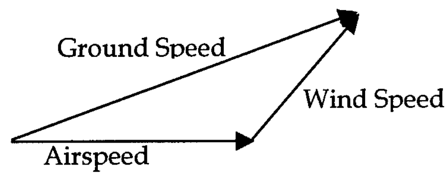

Figure 3: Relationship between Airspeed and Ground Speed

A possible solution for determining wind speed, whilst the helicopter is flying at speeds greater than 30 knots, is to obtain the airspeed from the pitot system and the ground speed from the GPS, and then determine the wind speed vector. Assuming that the wind speed stays relatively constant during short periods whilst the helicopter is travelling below 30 knots, an estimation of the airspeed can be obtained via the GPS by adding the last "wind speed vector" to the GPS ground velocity.

The accuracy of this system is dependent on the ability of the GPS to accurately measure ground velocity and the validity of the assumption that the wind speed vector is relatively constant during the times that the airspeed decreases below 30 knots.

This report examines the ability of the GPS to provide velocity data of acceptable accuracy. Examining the assumption about the constancy of the wind speed vector will be part of future work.

1.4 Overview of the GPS

The GPS consists of 24 satellites (21 navigational satellites and 3 active spares) that orbit the earth in 12-hour orbits. The orbit altitudes are such that the satellites repeat the same track and configuration over any point approximately every 24 hours. There are six orbital planes inclined at about 55° with respect to the polar plane with nominally four satellites in each. This configuration provides the user with between five and eight satellites visible at any point on earth.

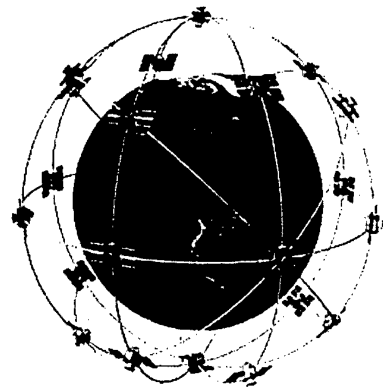

Figure 4: GPS - 24 Satellites covering the entire Earth

The GPS finds the position of the receiver via "triangulation", which means that three satellites are required to obtain a fix on the position. The satellites use an algorithm to send a unique time-varying message. The receiver, having the same message generation algorithm installed, continually tries to match its message with received messages. Since there is a time lag between when the message is sent from the GPS and when the receiver receives the message, the distance can be calculated by determining the time lag and assuming that the signal travels at the speed of light. With three satellites, the location of the receiver is fixed by the intersection of three spheres, which provide two possible points where the receiver could be. One of these points will be out in space and can be ignored; the other point will be the location of the receiver.

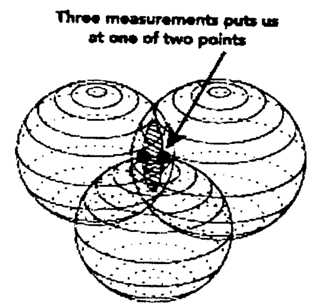

Figure 5: Triangulation gives two points - one can be ignored giving the location of the receiver

To determine the time lag from transmission to reception there is a need to have precise measurements of time. The satellites maintain atomic clocks for this purpose but to provide such a system in a hand-held receiver is not viable. To overcome this, a fourth satellite is used, and a fourth variable, time, is added to the equations. Figure 6 shows an example of how the time variable is used. The pseudo ranges of satellites A and B intersect at point XX, but satellite C's pseudo range does not go through that point. This discrepancy alerts the receiver that the clock in the receiver is not exactly the same as those in the satellites. Since any clock error or offset would affect all calculations of distance from the satellites equally, the receiver looks for a single correction factor that would allow all the measurements to intersect at one point. For example, as shown in Figure 6, by subtracting a second from each measurement the ranges all intersect at one point. With the correction factor determined, the receiver can then apply the correction yielding both a position and an accurate updated clock time at the receiver. This calculation is carried out for every solution, with the receiver's updated clock used in the calculation of the solution if only three satellites are available. The receiver clock is thus synchronised to the universal time from the GPS satellites.

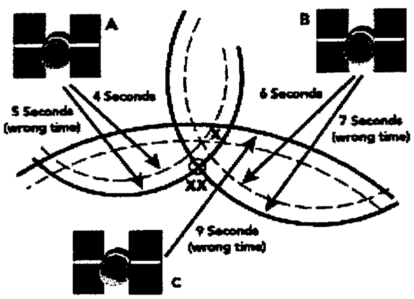

Figure 6: Timing error - use fourth satellite to correct.

There are two versions of GPS that may be provided: the Standard Positioning System (SPS) for civilian use and the Precise Positioning System (PPS) for use by the US military and its allies. The SPS system can be actively degraded by the US Department of Defense via a process known as "selective availability", which yields positional errors of the order of 100m. Since May 2000, selective availability has been removed and errors in the SPS are now less than 10m.

Apart from the selective availability, the GPS signal is degraded by several other factors. These include noise at the receiver, inaccuracies in the receiver clock and the GPS clock, troposphere/ionosphere interference, and multi-path errors (where the signal arrives at the receiver by additional reflected paths).

Even without deliberate or natural signal degradation, a major factor affecting GPS accuracy is satellite geometry. This is the relative positioning of the satellites with respect to the GPS receiver. If the GPS receiver is locked onto four satellites and all four satellites are in a similar general direction from the receiver, satellite geometry is poor. In some cases, the GPS receiver may be unable to provide a position reading as all the distance measurements are from the same general direction. This means triangulation is inaccurate and the common area where these distance measurements intersect is relatively large (Figure 7). With the same four satellites separated equally at approximately 90-degree intervals (eg. north, east, south, west), the common area where all four distance measurements intersect is much smaller, providing much more confidence in the location measurement (Figure 8). This is known as Geometric

Dilution of Precision (GDOP). GPS receivers use an algorithm to select the best four satellites, with respect to their position, to minimise the GDOP. The satellite geometry becomes an issue when using a GPS receiver in a vehicle, near tall buildings, or in mountainous or canyon areas, as several directions are blocked, thereby limiting the available satellites.

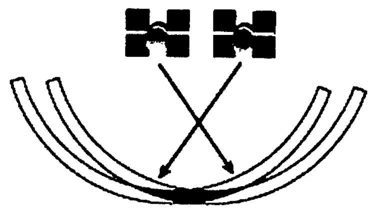

Figure 7: Poor GPS Satellite Geometry - large area

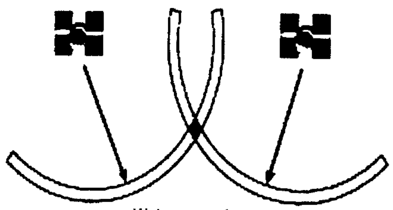

Figure 8: Good GPS Satellite Geometry- small area

1.4.1 GPS Velocity Measurement

Receiver velocity can be obtained by calculating change in distance over time, the satellite Doppler frequency shift or both. However, this may be receiver dependent and it is not easy to discern what method a particular receiver uses. In most second-generation GPS receivers, the primary form of velocity calculation is Doppler measurements on the carrier signal. Reference 1 describes this as follows: "*The doppler offset of the satellite carrier signal is caused by the relative velocity, along the line of sight, between the user equipment and the satellite. The carrier tracking loop adjusts the receiver-generated frequency until it matches the incoming carrier frequency determining the relative velocity between the satellite and the receiver. Using four relative velocities with four satellites, the receiver then calculates its velocity in earth-centred-earth-fixed (ECEF) system coordinates*". The velocity is calculated by integrating the Doppler shift with respect to time over one-second intervals. The GPS velocity estimated each second is then the average of the velocity over the previous second and its accuracy is therefore dependent on the satellite geometry and the motion of the vehicle in which the receiver is located. (Ref. 4).

2. GPS Velocity Accuracy Trial

A trial was conducted to determine the accuracy of a low-cost GPS receiver in dynamic situations. This trial was conducted using a GPS mounted in a vehicle, together with a data acquisition system and an interface into the vehicle speedometer/odometer.

2.1 GPS Receiver:

The GPS receiver used was the Trimble Ensign XL (Figure 9). This receiver is a three-channel receiver capable of tracking up to eight satellites. With a valid position fix this receiver will update position, course and velocity at between 1.5 and 5 second intervals. A remote antenna (mounted on the roof of the vehicle in our trial) allows the receiver to be used within an enclosed area, like a vehicle, that would otherwise block much or all of the GPS signals (Figure 10). The receiver is able to output various GPS data, such as position and velocity, via a serial interface. This output uses the NMEA (National Marine Electronics Association) 0183 protocol.

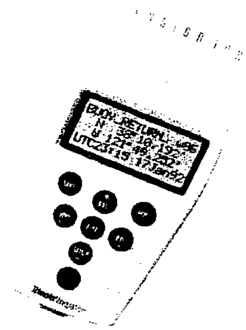

Figure 9: Trimble Ensign XL

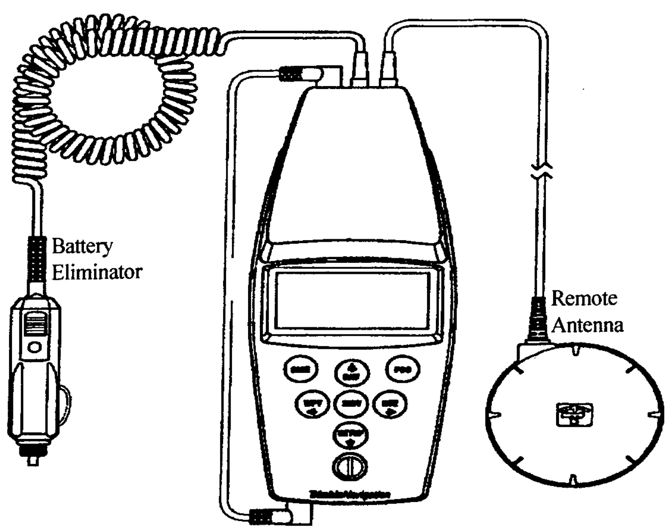

Figure 10: GPS - Accessories Used

The NMEA 0183 protocol covers a range of navigation information, broken into discrete messages. The Ensign XL transmits 13 of these messages (Appendix A). Of these 13 messages only 6 were logged as they contain all the information required for this investigation.

2.2 The Software

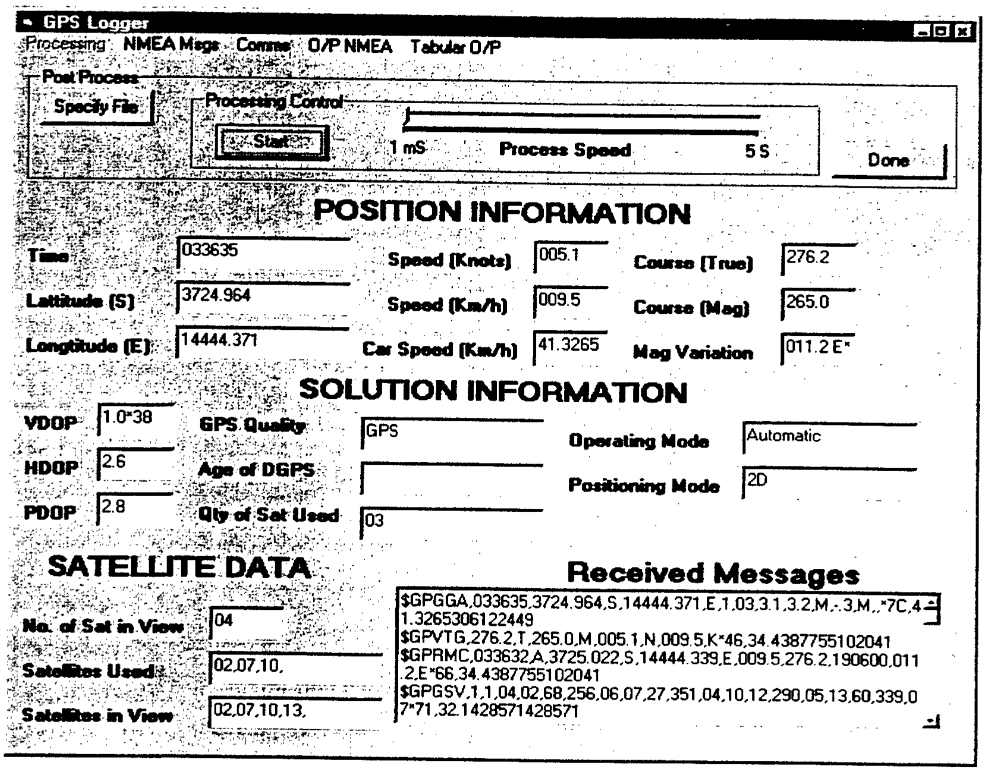

Figure 11: Screen Capture of the GPS/Velocity Logger

Software was written by the authors, using Visual Basic, to capture the NMEA messages from the GPS receiver. These messages were broken down to provide the appropriate pieces of information to be displayed to the user (Figure 11). The raw data were also saved to disk for subsequent analysis. In addition, the software was used to capture the instantaneous vehicle velocity as measured by the vehicle's odometer system.

The vehicle velocity was calculated by counting the number of pulses that the car odometer system generated per revolution of its wheels. The vehicle used was a Holden Commodore fitted with 205/65 HR15 tyres. With these tyres, the input signal to the odometer consists of 6272 pulses/km.

A WaveBook/512 data acquisition unit was used to count the pulses in a one second interval from the odometer system. The PC software read the data after each acquisition was complete and then converted them into velocity.

The software writes the output as a text file, either tab-delimited with the appropriate data extracted from the NMEA message, or as a modified NMEA message string. The modified message string contains the standard message data with the vehicle velocity attached to the end. This allows the data to be imported into other programs for analysis (such as Microsoft Excel) or post-processed using the software developed to replay the captured data.

2.3 Dynamic Performance Trial

A test program was developed to measure the dynamic capabilities of the GPS receiver. Of particular interest is the ability of the receiver to continually provide correct velocity data in response to rapidly accelerating and decelerating conditions whilst manoeuvring tightly. In addition, data were collected to try and determine the methodology that the receiver uses for calculating velocity. In all cases the GPS position and velocity were recorded, together with the vehicle velocity from the speedometer. Additionally, the identification of the satellites used for each solution was recorded.

The tests were conducted at the ATEA Proving Ground at Monegeetta (Appendix B). The area was sparsely populated with little tree cover. The tests were conducted on sealed roads, the braking strip and on the skid pan/handling circuit.

The test program conducted was:

Static Satellite Acquisition -	facing North, East, West
Linear Acceleration -	0 to 100km/h
Constant Speed Turns -	25km/h, 40km/h, 60km/h
Accelerated Turns -	0 to 40km/h, 60km/h
Positional Test -	along first class road to determine the algorithm for velocity determination
Braking	100km/h to 0 at two levels of deceleration

2.4 Results

The results obtained are discussed in the following sections. Only some of the results are shown graphically here. The full list of graphs is provided in Appendix C.

2.4.1 Static Satellite Acquisition:

This test was conducted to simulate the re-acquisition of satellites after an obstacle, such as certain features of the terrain, has blocked them. The GPS receiver was allowed to obtain its maximum number of satellites before totally covering or disconnecting the antenna so that it lost reception of all satellites. The time taken for re-acquisition was then measured after the antenna was uncovered or reconnected.

All satellites were re-acquired relatively quickly taking, at most, 4 seconds per satellite. An interesting observation is that the number of satellites acquired by the GPS receiver was the same irrespective of the direction the antenna was facing.

Satellites Before	Satellites After	Time to Re-acquire	Notes
8	8	22 seconds	Facing West
8	8	11 seconds	Facing North
8	8	14 seconds	Facing East
8	8	28 seconds	Disconnected for a longer period of time (30secs)

2.4.2 Linear Acceleration to 100 km/hr:

This test was conducted to determine the amount of time lag in the GPS velocity measurement for an instantaneous velocity. The acceleration to 100 km/hr was done at three arbitrary accelerations: low, medium and hard.

No. of Satellites Before Acceleration	Satellites Lost During Acceleration	Acceleration	Time 0- 100 km/hr
8	None	Hard	15 seconds
8	None	Medium	20 seconds
8	None	Slow	30 seconds
8	None	Hard	13 seconds

The measured car velocity data reached 100 km/hr as expected. The GPS velocity generally matched this well though in some cases the velocity did not reach 100 km.

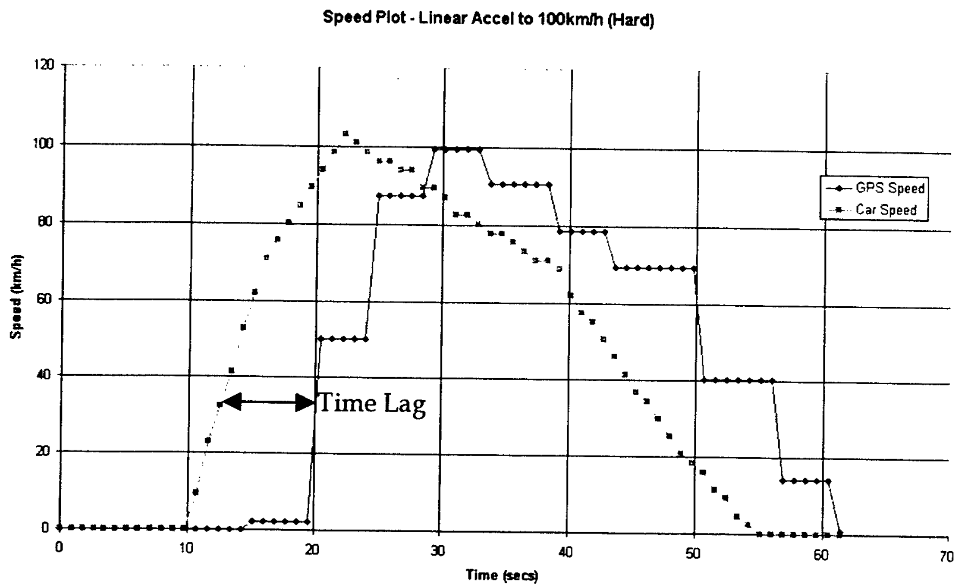

Figure 12: Speed Plot for Hard Acceleration to 100 km/h

From the velocity plot (Figure 12) it can be seen that there is a time lag between the car velocity and the GPS velocity. The GPS generally lags behind the car velocity by approximately 5 seconds. Although the GPS manual indicates an update rate of 1.5 seconds, the measured data does not support this; the actual update rate varying between 4-10 seconds, with an average of 5 seconds. The plot also shows that the receiver transmits the last known solution until a new solution is obtained.

2.4.3 Constant Speed Turns

This test was conducted to determine whether satellites would be lost during manoeuvring and, if so, what affect this would have on the velocity solution. The antenna was positioned on the forward slope of the vehicle roof at an inclined attitude so that only a portion of the sky would be visible to the receiver. By manoeuvring the vehicle the portion of the sky visible would be constantly changing. The constant speed turns were conducted by engaging the cruise control, where possible, at the desired speed and steering the vehicle in the tightest continuous turn possible for that speed. The turns were conducted at speeds of 25 km/hr, 40 km/hr and 60 km/hr. A variable speed test, where the cruise control was not set, was also conducted.

Figure 13 indicates that the average GPS velocity was similar to the vehicle's speed. However, the instantaneous speed is not accurate with the GPS showing a ±10 km/hr variation compared to the car speed in some cases. This could be due to the slow update rate of the receiver, or the fact that the car was travelling in a circular path resulting in the Doppler frequency shift varying significantly within the one second integration period in relation to each satellite, or to changes in satellites used during the solution.

Figure 14 attempts to graphically represent the satellites used by the receiver in determining its solution. For each solution the identification number (1 to 24) of each of the satellites used in that solution is transmitted by the receiver. These satellite identification numbers have been added together so that when a different satellite was used or one was dropped, it is likely that the sum would change.

An examination of the satellites used in each solution (Figure 14) shows a good correlation between changing satellites and a large speed variation. However, there is a likely chance that the large speed variation is partly due to the time lag before a "new" solution is updated from the receiver. An interesting note is that the effect of the loss of one satellite within the solution (i.e. going from four to three satellites) is negligible compared to the effect of switching satellites. This implies that, for some satellite geometries, a particular satellite may be crucial for the GPS receiver to obtain a solution, while other satellite geometries are more robust.

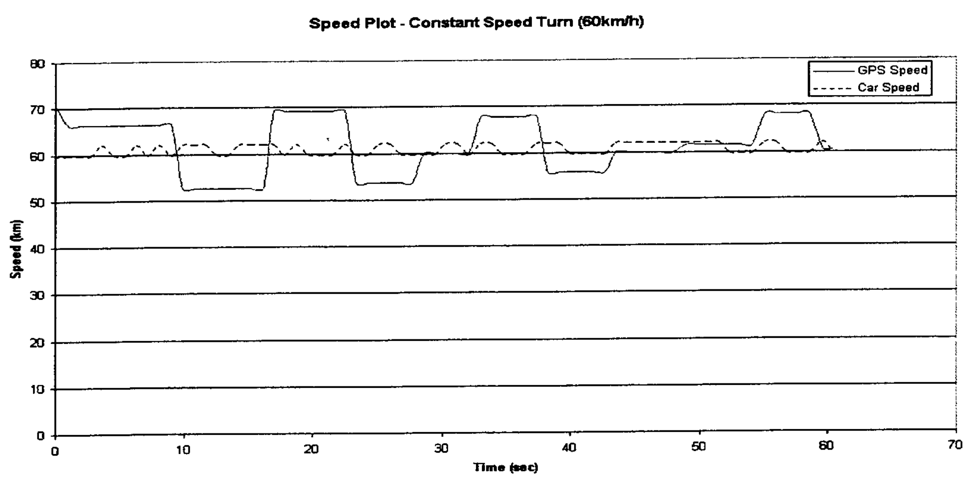

Figure 13: Speed Plot for Constant Speed Turn at 60 km/hr

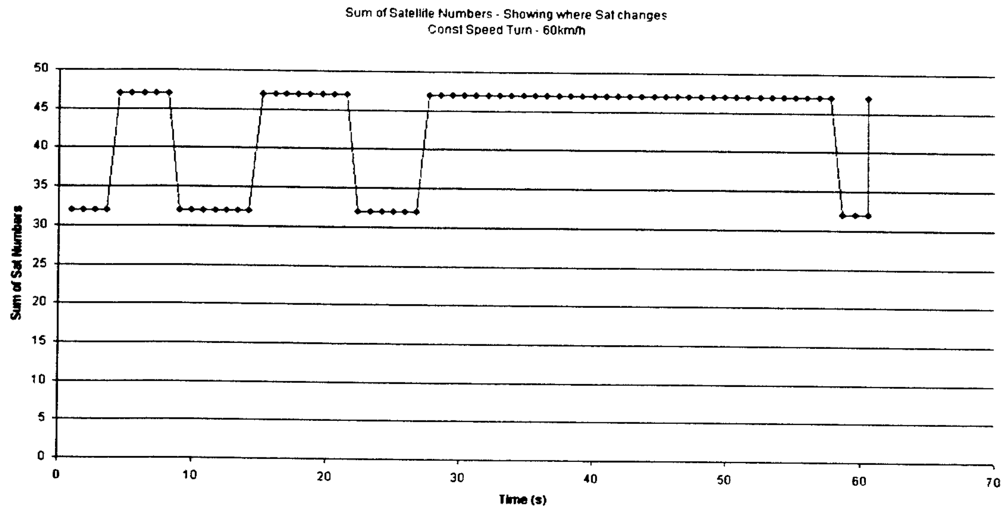

Figure 14: Plot Showing Changes in Satellites being used for Solution

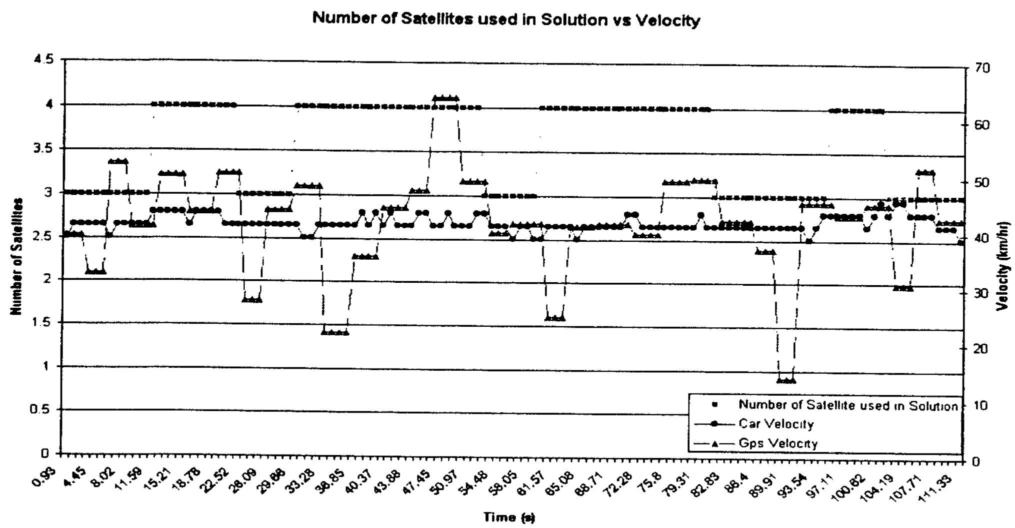

Figure 15 : Example of Number of Satellites being used in Solution is negligible. The GPS velocity changes even when the number of satellites used in the solution is constant.

Figure 16 shows that the GPS receiver is generally capable of giving a correct heading, as well as speed. It is assumed that the GPS heading is calculated by knowing the relative velocities of the receiver to each satellite in the solution, via the Doppler shift, and determining the velocity vector. It should be noted that that the vehicle heading was not measured with a sensor, but has been calculated after the trial by computing it based on successive positional fixes provided by the receiver.

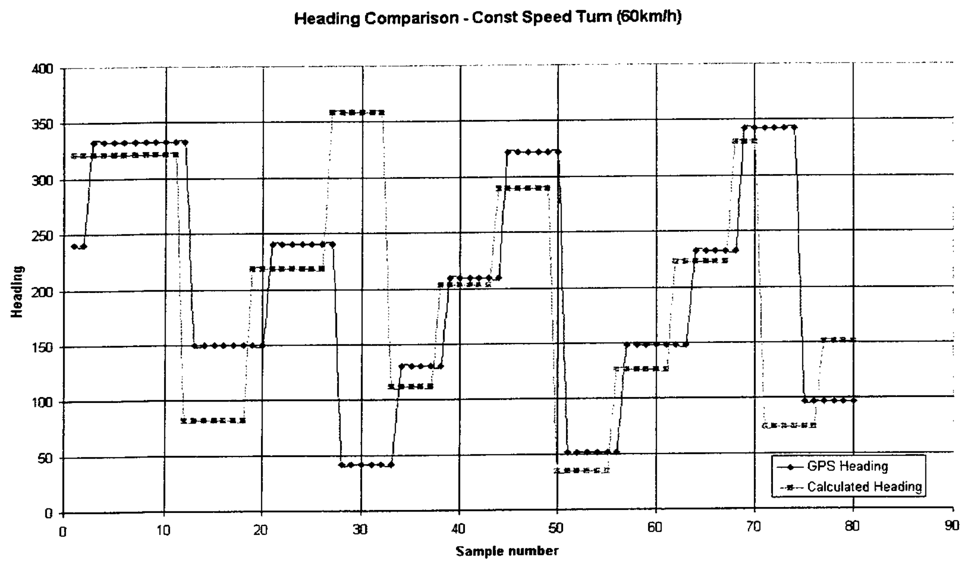

Figure 16: Heading Plot for Constant Speed Turn at 60 km/hr

2.4.4 Accelerated Turns

Accelerated turns were done from a standing start to 40 km/hr and 60 km/hr. All the data obtained showed that the receiver continually had four satellites for its solution and there were no changes in the satellites used for a solution in each of the test runs.

The velocity results (Figure 17 and Appendix C) show the same characteristics as the previous results with a time lag between 4-5 second.

The calculated and GPS heading results (Figure 18) once again are reasonably consistent.

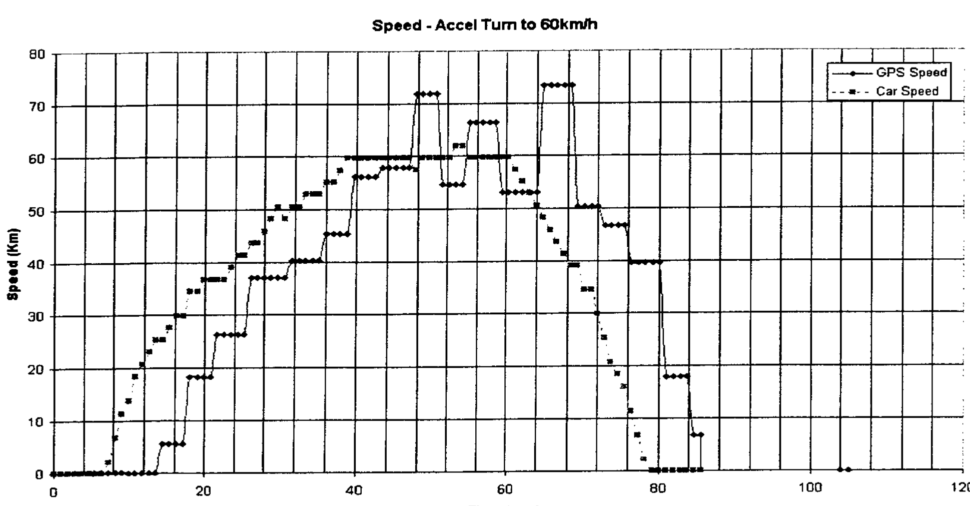

Figure 17: Speed Plot for Accelerated Turn to 60 km/hr

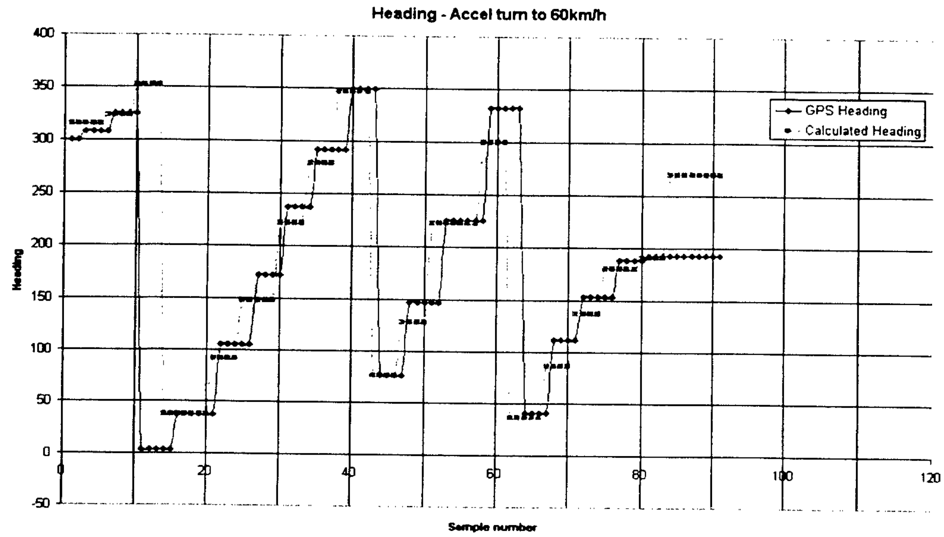

Figure 18: Heading Plot for Accelerated Turn to 60 km/hr

2.4.5 GPS Velocity Algorithm Determination

To determine whether the GPS receiver was using *change in distance over time* to calculate velocity, the distance between each point was calculated from the GPS latitude/longitude results. This distance was then used to calculate the velocity.

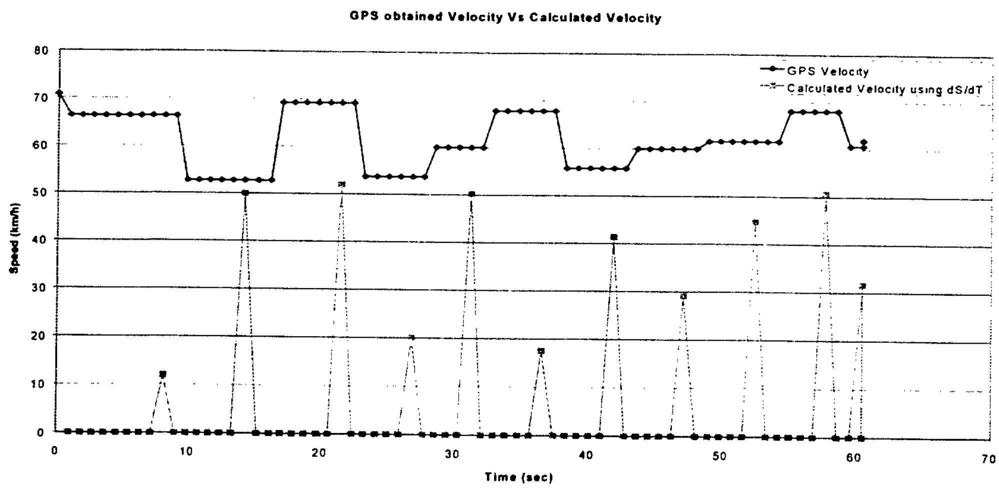

Figure 19: Velocity Comparison: GPS output versus calculated velocity based on GPS dS/dT

It can be clearly seen in Figure 19 that the receiver does not calculate velocity using the dS/dT (change in distance over change in time) method. It should be noted that the data are discontinuous as well. Between solution updates the receiver outputs its last known solution, yielding the many instances when the position and velocity are constant and hence the dS/dT calculation is zero.

Figure 20 is the same plot with the calculated velocity held constant to account for the time lag of the GPS receiver (ie. since we know that we are constantly moving

then the velocity should not be zero. Therefore we hold the last known velocity calculated until we get a new change in distance over change in time solution). The result is only slightly better than that in Figure 19. Hence, the calculated velocity does not track the GPS output closely enough to conclude that the receiver uses this method. It can also be seen that the points, where there is a sudden large drop in velocity, matched the times where there was a change in satellite for the solution as previously mentioned. These results tend to indicate that the receiver uses a shift in Doppler frequency to obtain the velocity of the receiver.

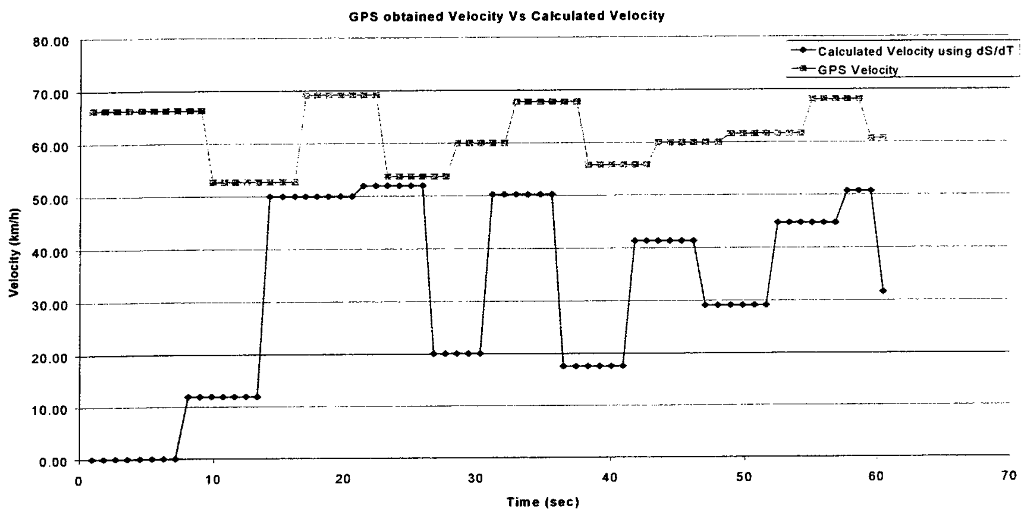

Figure 20: Velocity Comparison: GPS output versus calculated instantaneous velocity

2.4.6 Circuit Run

Normal variable driving was conducted around the First Class road circuit to simulate normal flight. Two runs were performed separated widely by time, to ascertain the effect of having different satellites used in the solution.

Figure 21 shows that the general shape, length and width of both circuits (termed AM and PM), as calculated by the GPS, are similar and compare well with the actual map. The small differences could be attributed to the different satellites used in the solution, the actual location or geometric position of the satellites, the accuracy of the GPS itself and the variability of where and how the car was driven.

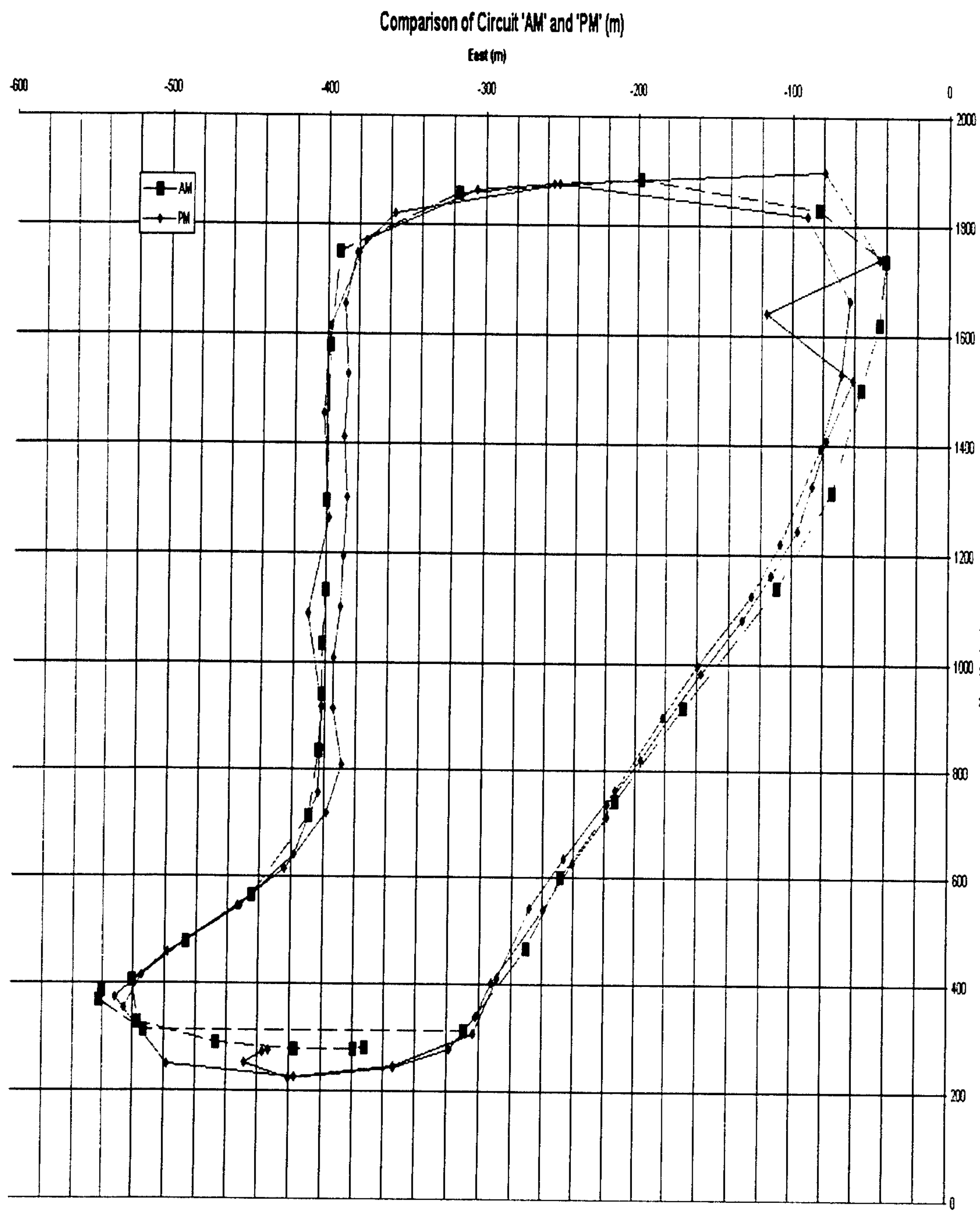

Figure 21: Comparison of the AM and PM circuits

It was noted that for the PM circuit that there are some erratic results (Figure 22 - as circled). Analysis of the data indicates that the erratic behaviour was due to changes in the satellites being used to obtain the solution.

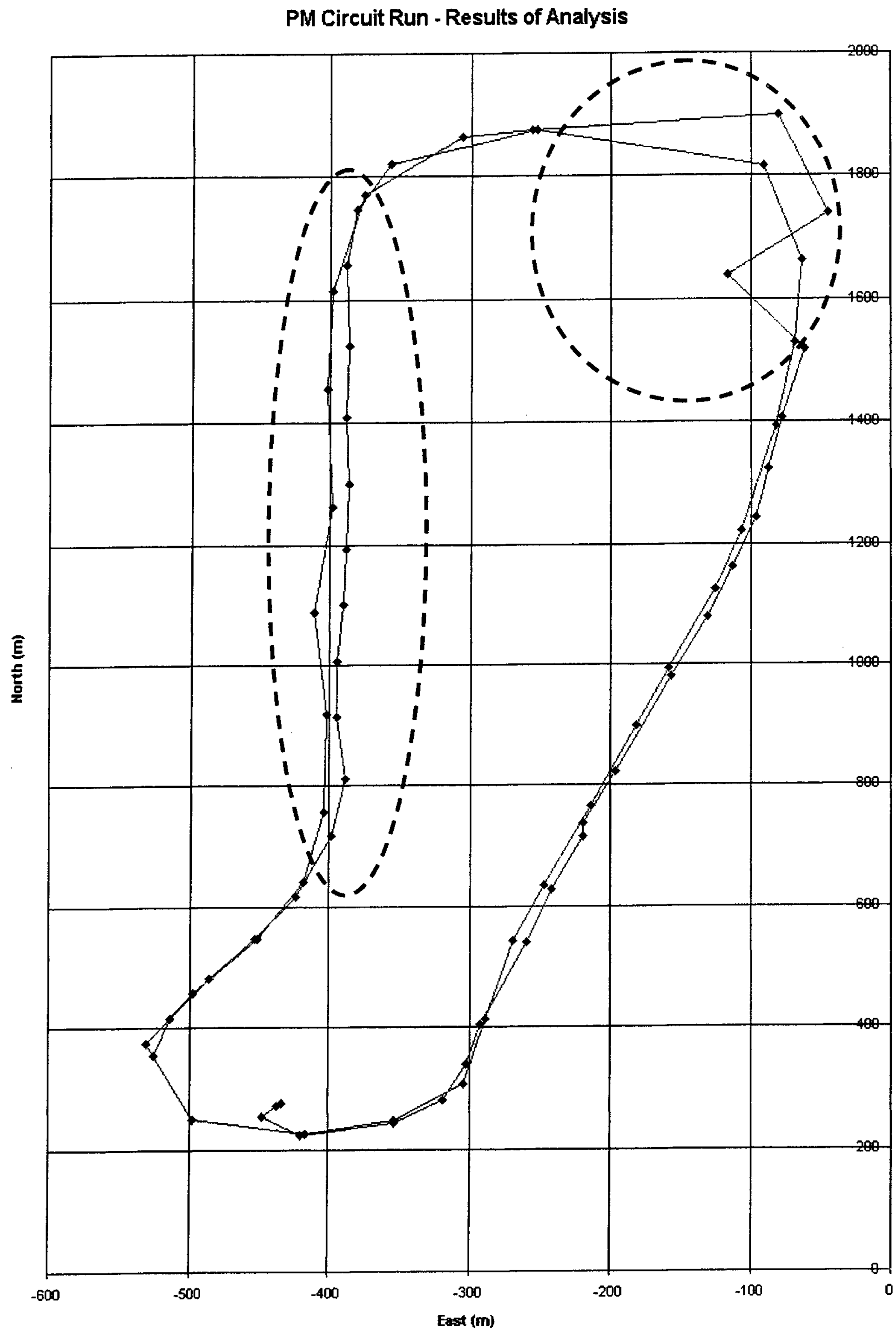

Figure 22: Circuits AM and PM: The circled areas indicate erratic results due to satellite changes

The velocity data (Figure 23) are good with the expected time lag and other related issues mentioned previously. Again, where large differences occur, these correspond to times when there was a change in the satellite used to obtain the solution.

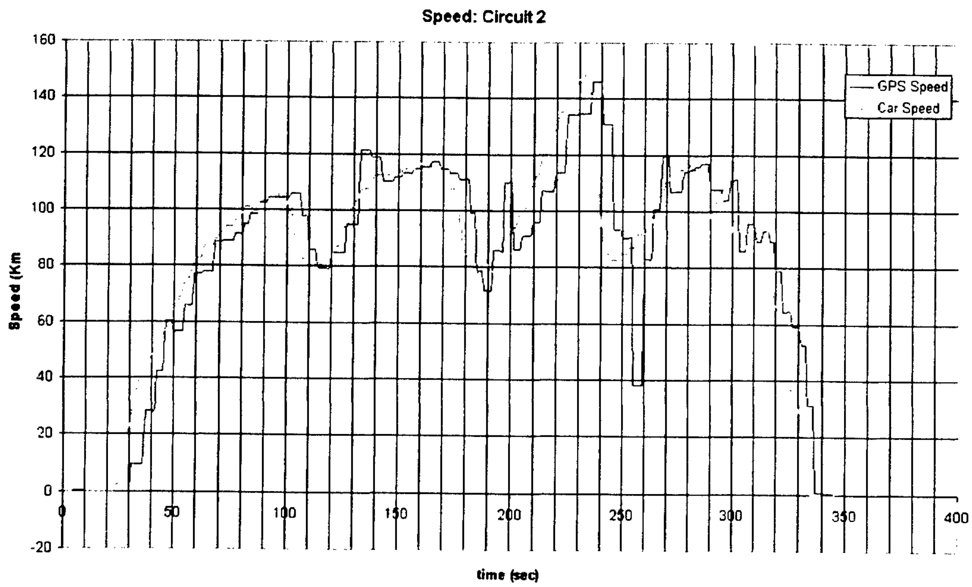

Figure 23: Speed Plot for the Entire PM Circuit

3. Conclusion

The velocity results obtained via the GPS match well with the measured velocity of the vehicle even in a dynamic environment. Some observations from the trial are:

- The GPS velocity is not determined by using change in distance divided by change in time. Hence, as supported by Ref. 1, we conclude that the velocity is obtained by using the Doppler shift of the carrier frequency.
- The velocity solution can momentarily become inaccurate whilst switching between satellites.
- The loss of a satellite, from four to three, provides fewer problems than the switching of satellites as described above.

The problems of inaccuracy that arise whilst changing satellites may be reduced in updated receivers which now routinely track up to 12 satellites or by receivers designed for use in a dynamic environment.

Overall, the GPS is a viable system to use to obtain the ground speed of a helicopter and hence has promise in being used as part of a low-airspeed sensor. However, the following need to be considered in any such sensor:

- The algorithms used must be able to handle the transient and sometimes erratic results that a GPS outputs when it switches satellites. One possible solution is to ignore the GPS output for a certain period of time when the sensor detects that the GPS has switched satellites.
- The time lag measured between the vehicle speed and the GPS speed is several times greater than that claimed by the manufacturer of the GPS. The lag is large, but still acceptable. Newer GPS receivers will certainly be better in this regard.
- No attempt has been made to determine the effects of the possible loss of GPS signal in a more dynamic and obscured environment. A GPS antenna mounted on a helicopter would most likely have main rotor and/or tail rotor blades between it and the satellites that it is receiving signal from. This will have an effect on the quality and integrity of the signal reaching the receiver, but the question to be posed is whether the GPS can still provide an acceptable solution.
- The use of the GPS for a low-airspeed sensor requires an assumption that wind speed is constant during slow speed flight regimes for short periods of time. This assumption has not been tested in this report and would need to be validated before a GPS system could be used.

4. Acknowledgements

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Scott Dutton - for his technical advice and general recommendations for the report and acquisition program.

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Appendix A
List of Messages Output by the Ensign XL GPS

The following is a list of the messages output by the Ensign XL GPS receiver. There are 13 messages, and they comply with the NMEA (National Marine Electronics Association) 0183 protocol.

Message	Description
APA	Autopilot Format A
APB	Autopilot Format B
BWC	Bearing and Distance to Waypoint
*GGA	GPS Fix Data
*GLL	Latitude and Longitude
*RMC	Recommended Specific GPS Data
RMB	Recommended Navigation Information
*VTG	Actual Track and Ground Speed
XTE	Cross-Track Error
ZTG	UTC and Time to Destination Waypoint
*GSA	GPS DOP and Active Satellites
*GSV	GPS Satellite in View
WCV	Waypoint Closure Velocity

Note: asterisks indicate message logged and used for this test.

Appendix B – Map of ATEA Proving Ground

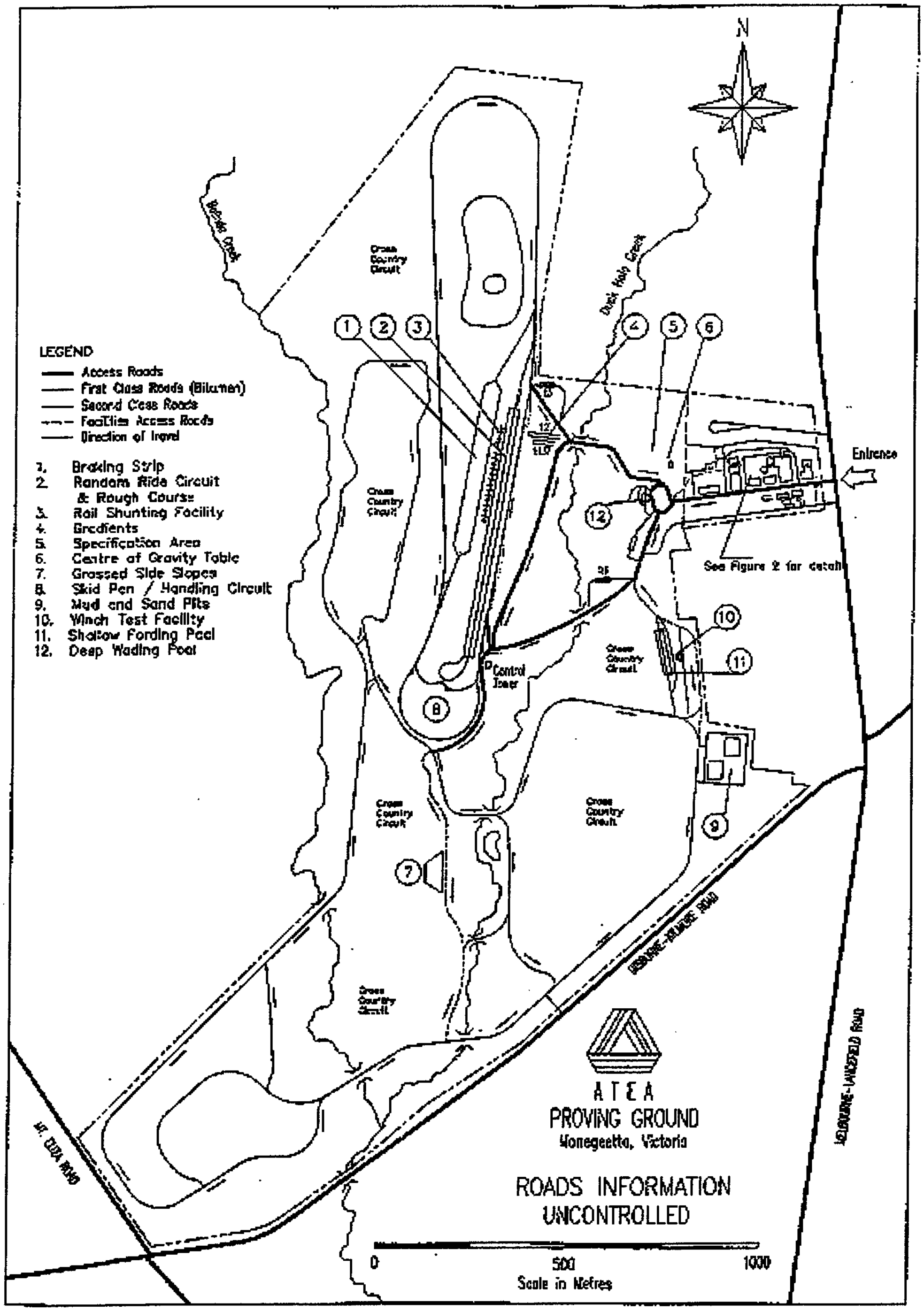

Figure 24: ATEA Proving Ground

Appendix C – GPS Results

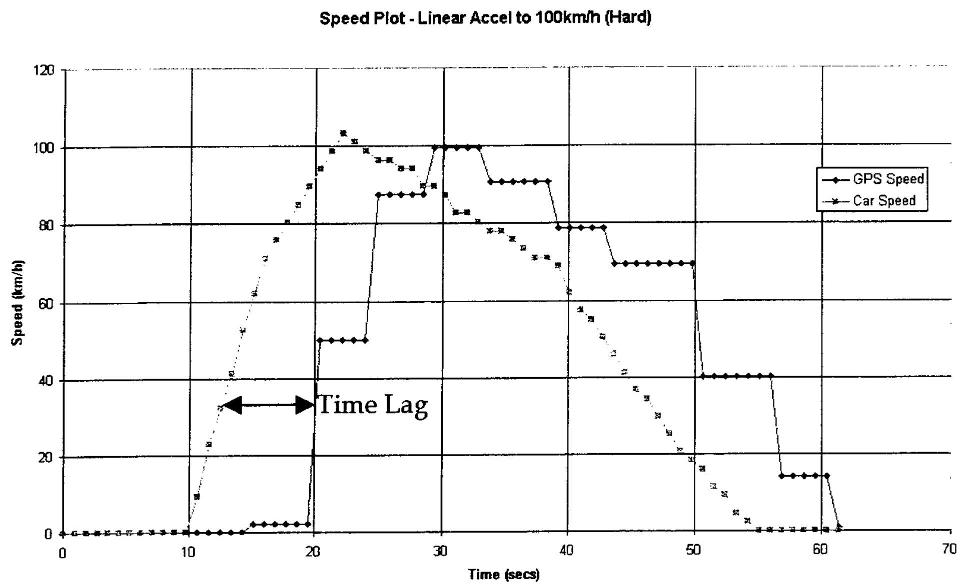

Figure 25: Speed Plot for Hard Linear Acceleration to 100 km/hr

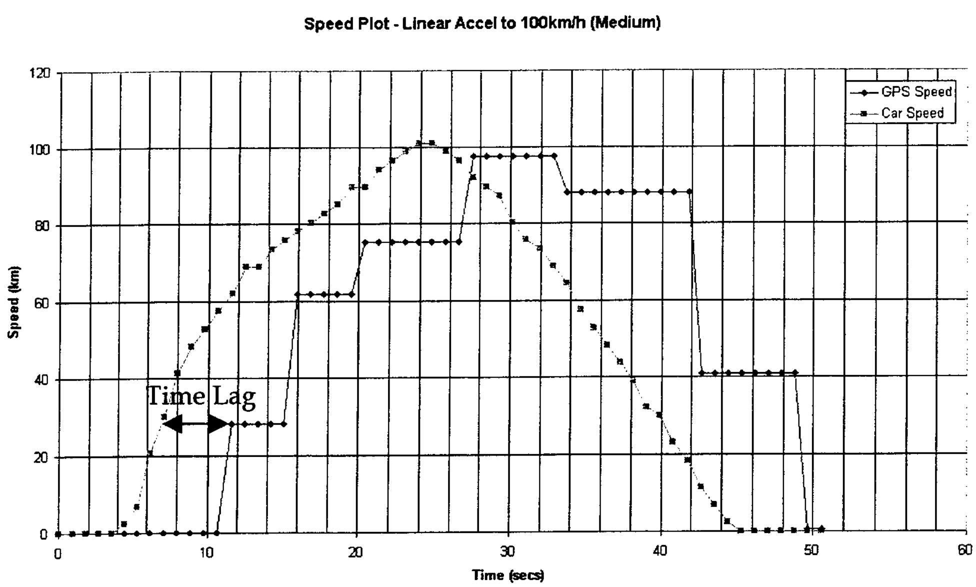

Figure 26: Speed Plot for Medium Linear Acceleration to 100 km/hr

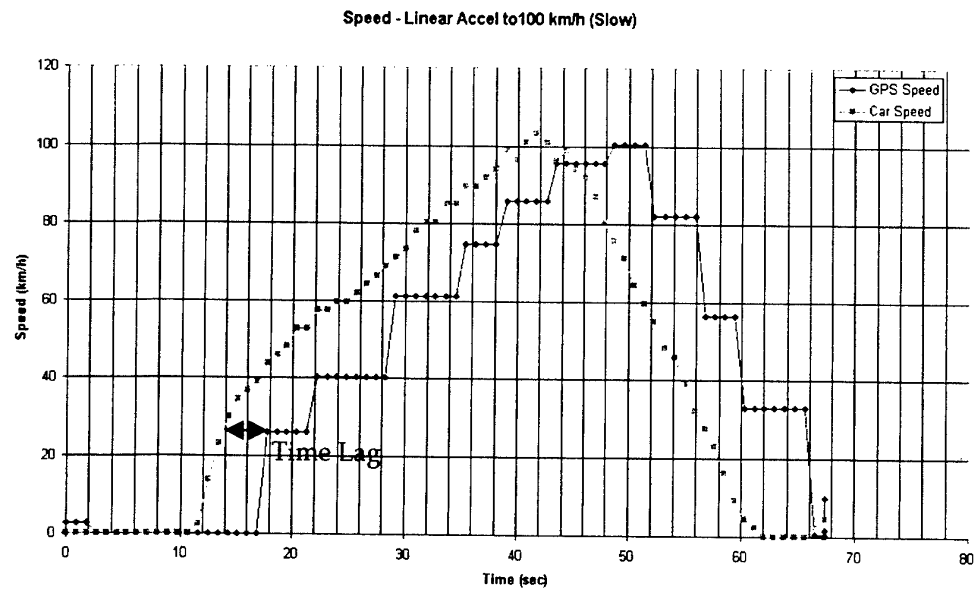

Figure 27: Speed Plot for Slow Linear Acceleration to 100 km/hr

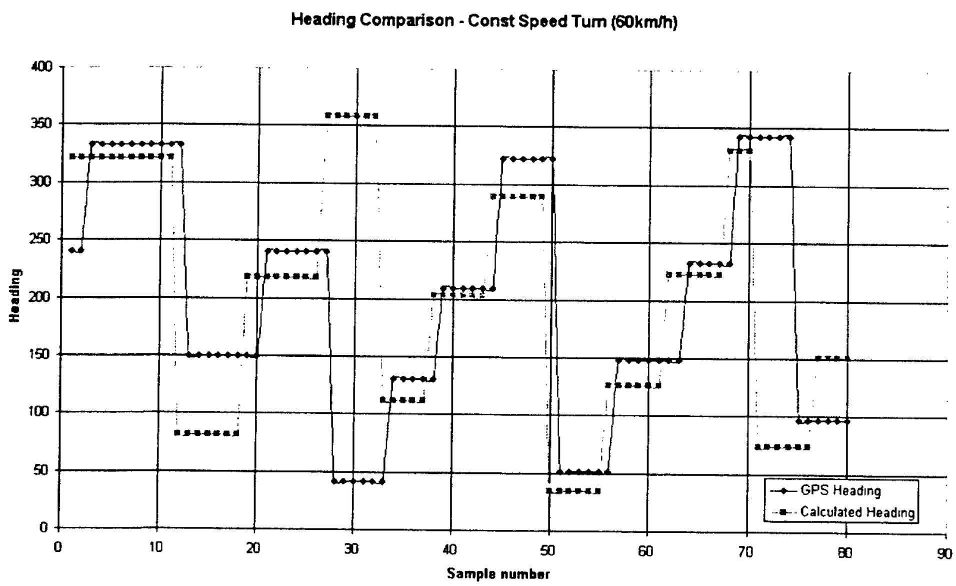

Figure 28: Heading Plot for Constant Speed Turn at 60 km/hr

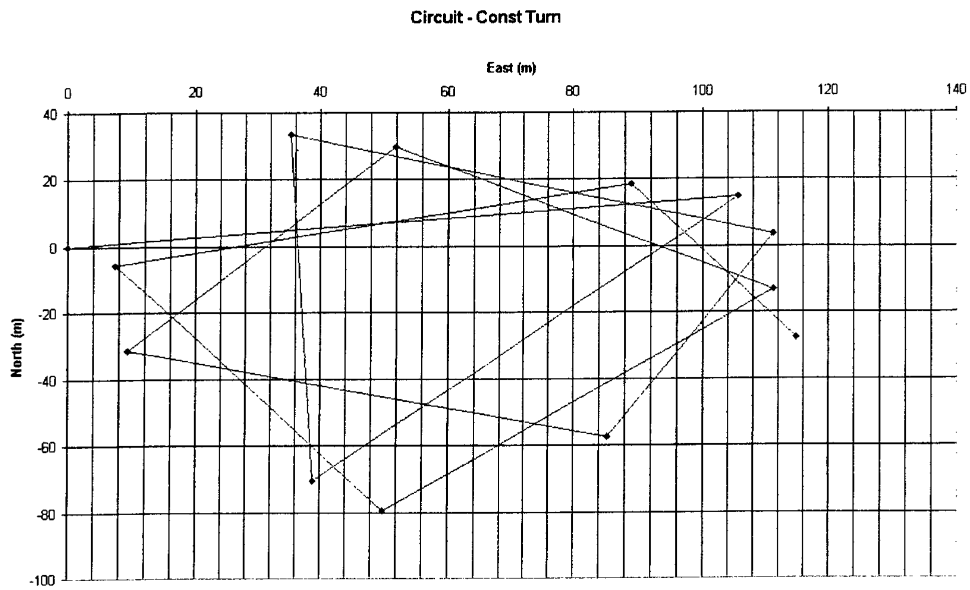

Figure 29: Circuit Plot for Constant Speed Turn at 60 km/hr

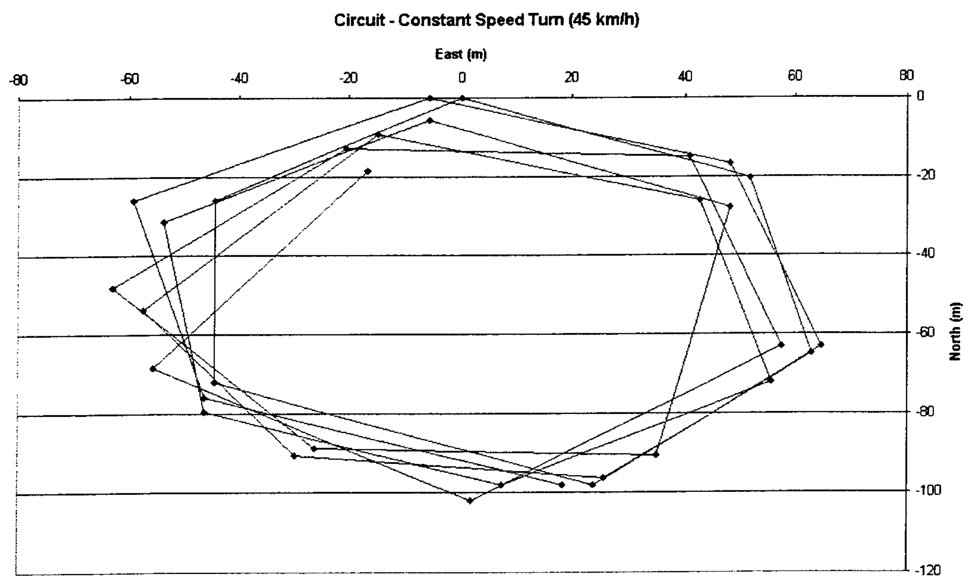

Figure 30: Circuit Plot for Constant Speed Turn at 45 km/hr

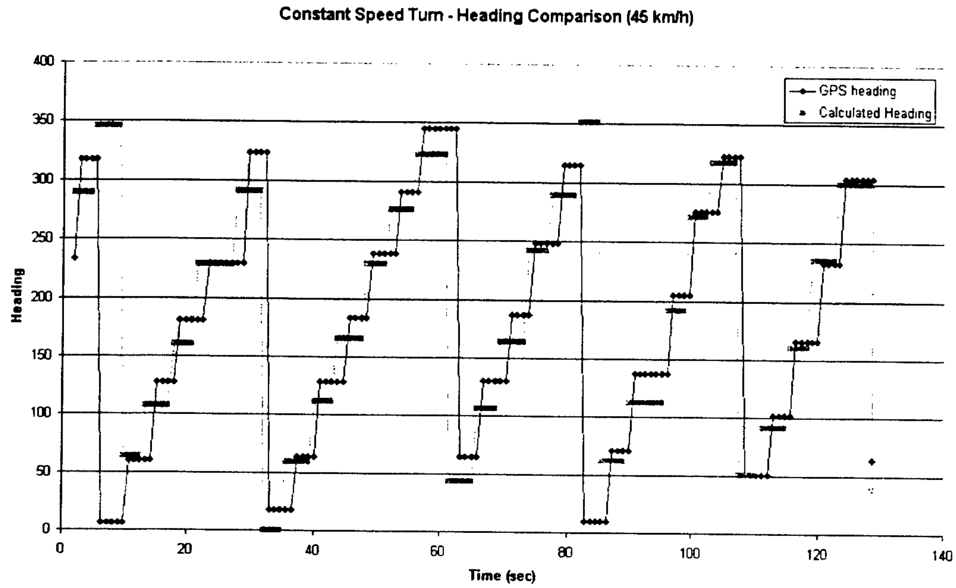

Figure 31: Heading plot for Constant Speed Turn at 45 km/hr

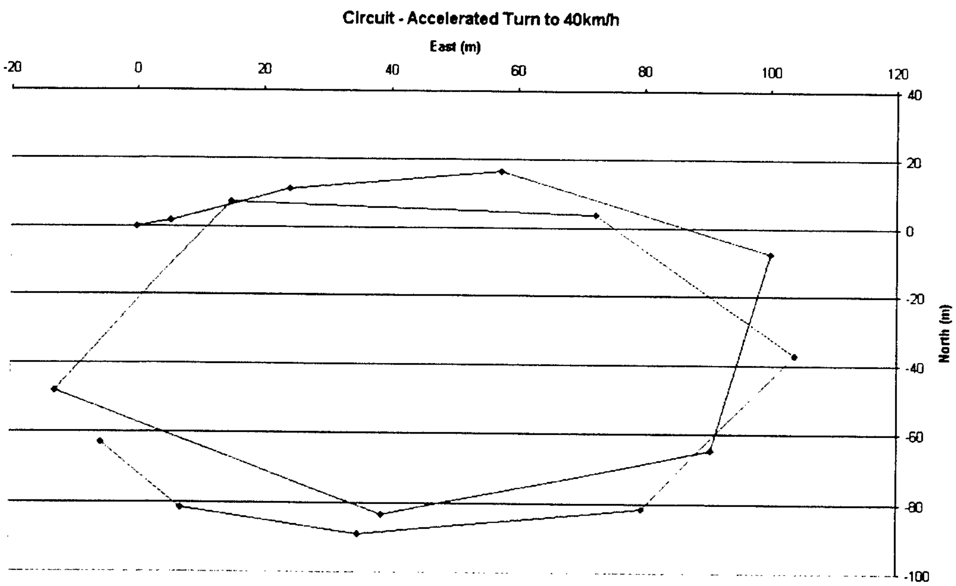

Figure 32: Circuit Plot for Accelerated Turn to 40 km/hr

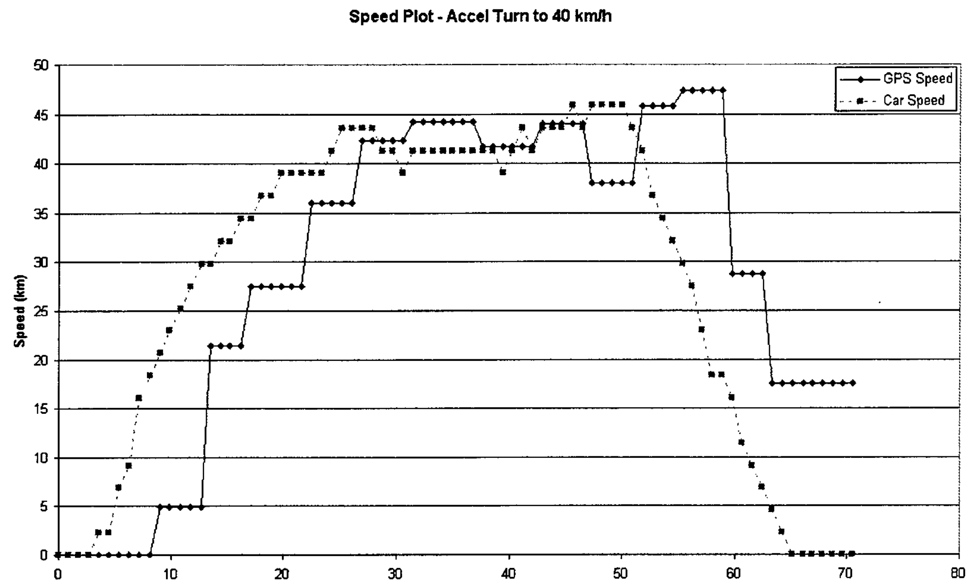

Figure 33: Speed Plot for Accelerated Turn to 40 km/hr

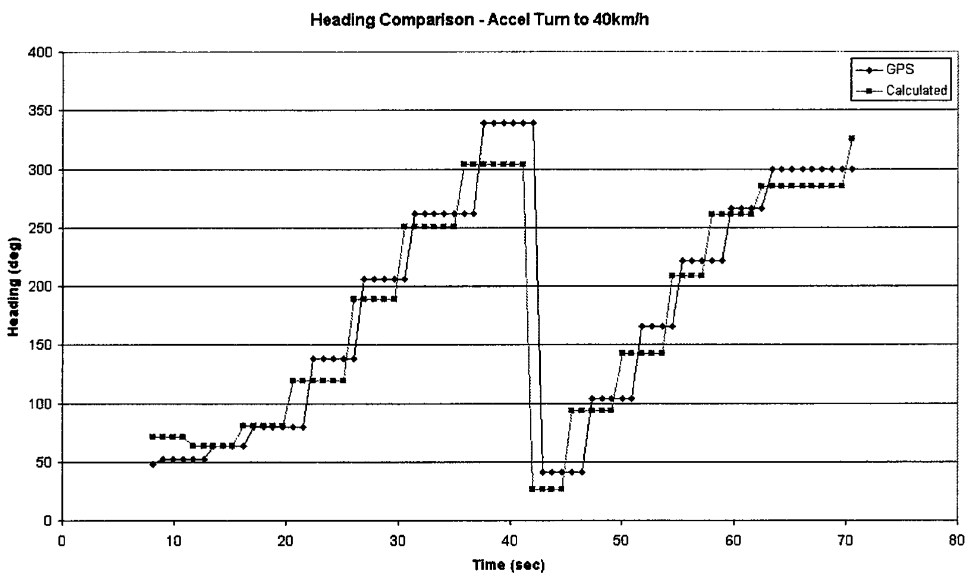

Figure 34: Heading Plot for Accelerated Turn to 40 km/hr

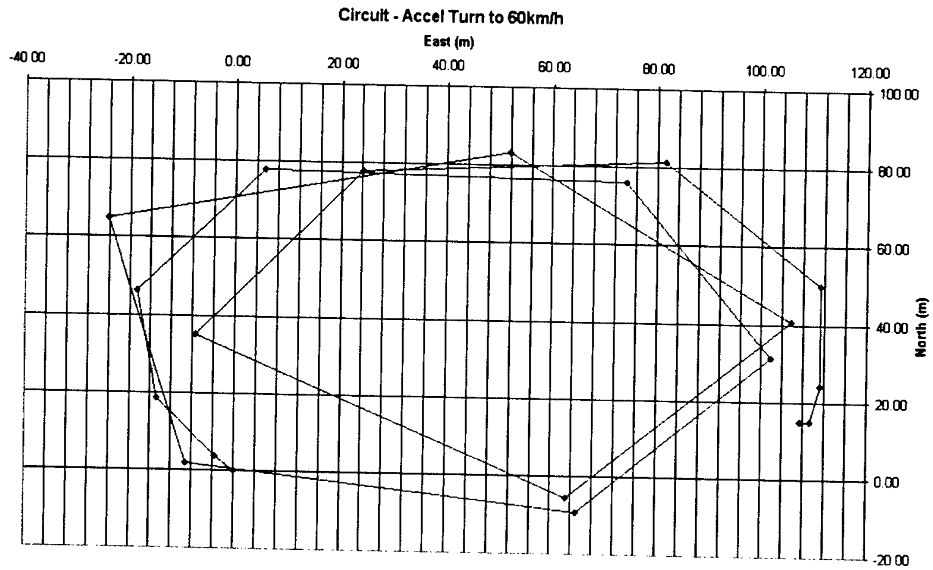

Figure 35: Circuit Plot for Accelerated Turn to 60 km/hr

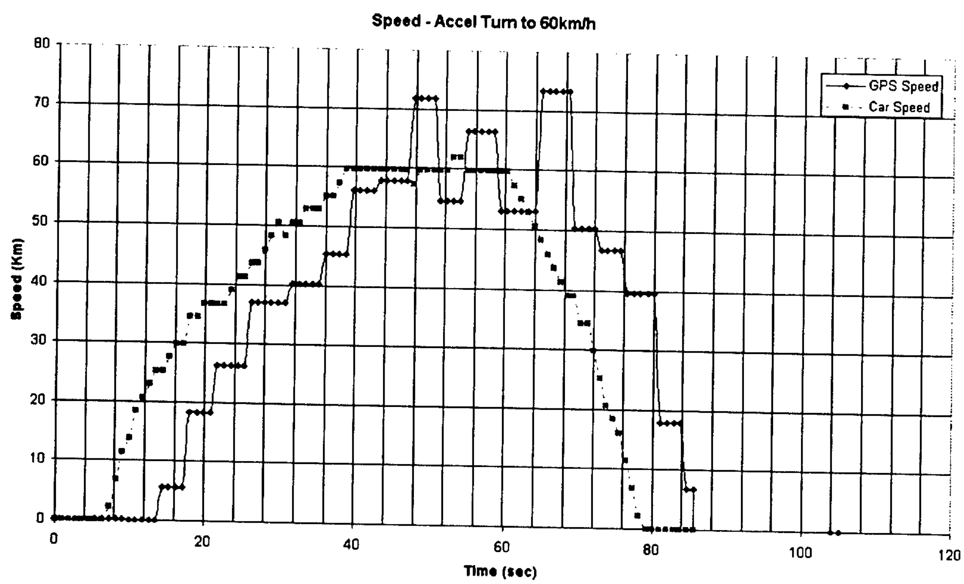

Figure 36: Speed plot for Accelerated Turn to 60 km/hr

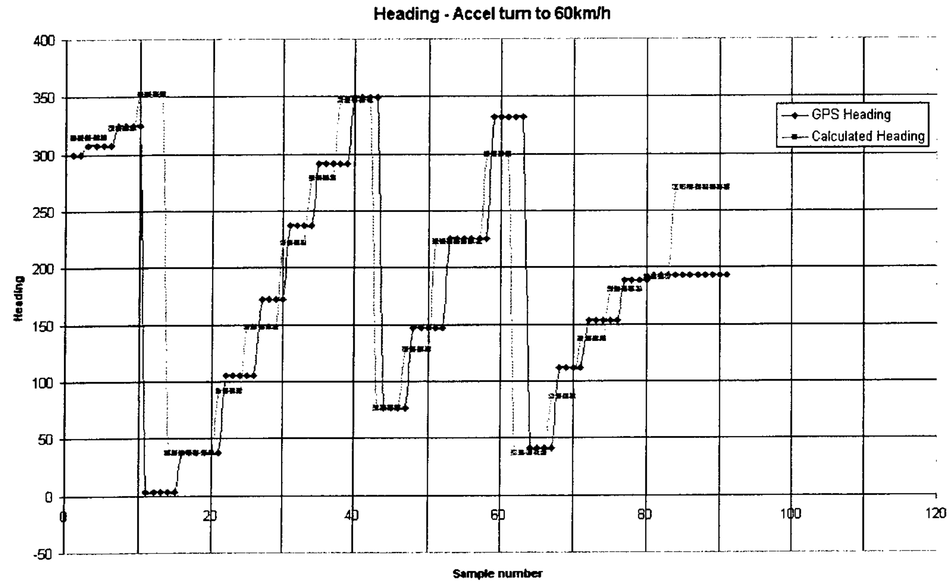

Figure 37: Heading Plot for Accelerated Turn to 60 km/hr

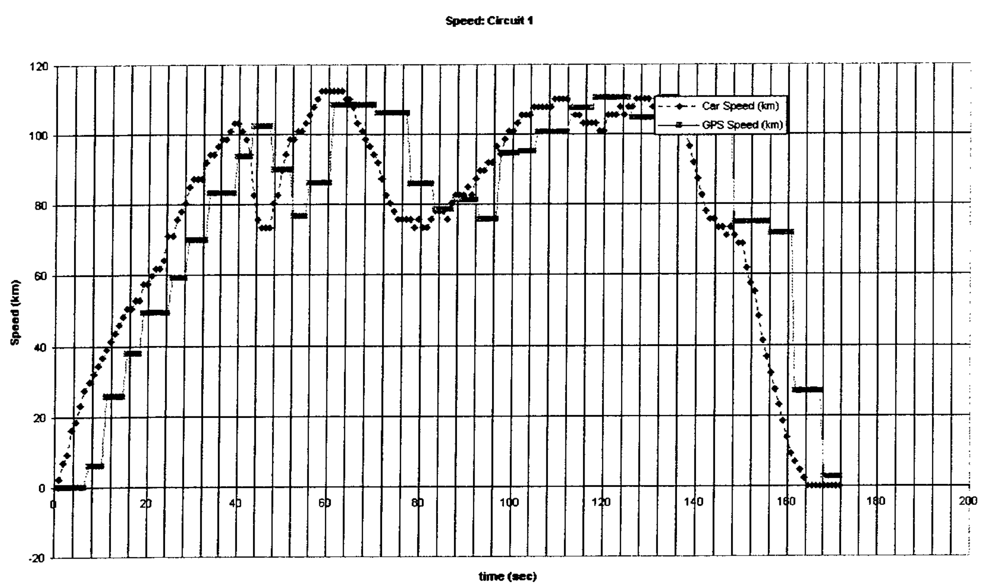

Figure 38: Speed Plot for the Entire AM Circuit

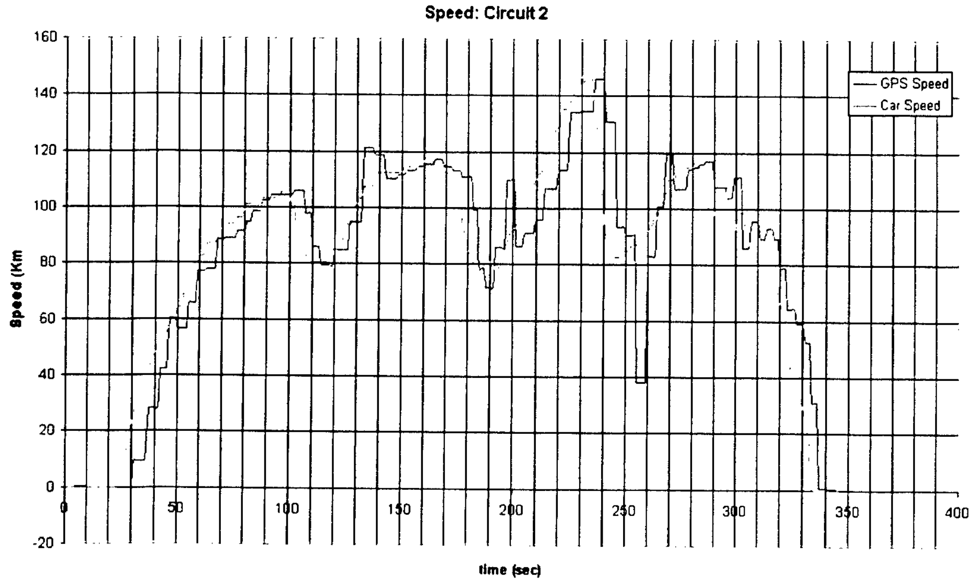

Figure 39: Speed Plot for the Entire PM Circuit

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Soon-Aik Gan, Scott Dutton, Chris knight

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19. ABSTRACT

This report focuses on the field trial of a GPS unit for measuring low helicopter airspeeds. The results indicated that the GPS has the potential to be used as a low-speed indicator. However, the possible loss of GPS signal, transient GPS results due to changes in satellites being used for the solution, time lag in the results and whether the assumption of a constant wind-speed is valid need to be considered.

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